NBSIR 84-2833

# Data Requirements for the Seismic Review of LNG Facilities



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National Engineering Laboratory
Center for Building Technology
Structures Division
Gaithersburg, MD 20899

Environmental Evaluation Branch
Division of Pipeline Certificates
Office of Pipeline and Producer Regulation
Federal Energy Regulatory Commission
Washington, DC 20426

June 1984

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**NATIONAL BUREAU OF STANDARDS, Ernest Ambler,** ***Director***

# PREFACE

This report describes data needed by the Federal Energy Regulatory Commission (FERC) for the seismic review of Liquefied Natural Gas (LNG) facilities and is intended to expedite the certification process of the FERC. It uses a format familiar to those industry representatives and their consultants who work on siting other safety related structures. Available state and Federal regulations were reviewed for format and type of information required to develop a source document which can be used to establish a consistent format and content for applicants in their submittal of the necessary geologic-structural-seismic information required to analyze sites for LNG facilities. Design criteria and levels of safety to be used in analyzing sites were not considered.

It is anticipated that this document will provide a guide and format for the applicant to thoroughly investigate the siting of LNG facilities and establish design criteria to be used. It will be the responsibility of the applicant to demonstrate the applicability and significance of the criteria he has selected for the site(s) being considered. All sections should be addressed by the applicant to ensure a thorough investigation for each proposed site although each section will not necessarily be appropriate in all instances.

The authors appreciate the cooperation and useful suggestions of Robert Arvedlund of the FERC during the preparation of this document.

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# 1. INTRODUCTION

## 1.1 SCOPE

On February 11, 1980, the U.S. Department of Transportation (DoT) issued "LNG Facilities' Federal Safety Standards" (49 CFR 193), providing minimum safety standards for the design and construction of liquefied natural gas (LNG) facilities. These are subsequently referred to as DoT safety standards. The National Fire Protection Association, an industry group, has prepared recommended standards for LNG facilities (NFPA 59-A, 1979 edition), which also require analysis related to earthquake hazards. Neither of these standards describes, in significant detail, what types of analysis are required to determine the acceptability of a site, the adequacy of the assumed level of earthquake hazard, or the adequacy of the proposed design to ensure integrity of the facility during the design earthquake. However, they do specify general performance criteria and some specific siting considerations. Additionally, the DoT safety standard includes a ban on the use of certain types of sites unless specific approval is granted by the Director of the Materials Transportation Bureau.

This report describes the nature of the investigations required to obtain the geologic and seismic data necessary to determine site suitability and facilitate design against the requirements of the DoT safety standard and the NFPA safety standard. It describes procedures for determining the quantitative vibratory ground motion design basis at a site due to earthquakes and describes information needed to determine whether and to what extent an LNG plant need be designed to withstand the effects of surface faulting. Other geologic and seismic factors required to be taken into account in the siting and design of LNG facilities are also identified.

Each applicant for a certificate shall investigate all seismic and geologic factors that may affect the design and operation of the proposed LNG facility regardless of whether such factors are explicitly included in this report. Additional investigations and/or more conservative determinations than those included in this report may be necessary for sites located in areas having complex geology or in areas of high seismicity. However, if an applicant believes that the particular seismology and geology of a site indicate that some of the information identified in this report need not be provided, that information should be identified in the application, and supporting rationale or data to justify clearly such departures should be presented.

This report describes a format for geotechnical and seismic design reports to accompany applications to the Federal Energy Regulatory Commission (FERC) to construct and/or modify and operate LNG facilities. FERC does not require use of the format although the review of applications will be simplified if a consistent format is used. However, if another agency requires similar information in a different format, the FERC staff does not require preparation of a new report re-written to comply with the format herein.

## 1.2 APPROACH

The approach followed in organizing these data requirements is drawn from that used by the U.S. Nuclear Regulatory Commission in the siting of power plants. It is felt that consulting engineers and those firms and individuals connected with energy in general are quite familiar with these data requirements and the engineering approach used. Thus, approaches in engineering and geological consideration for nuclear plants were adapted to the siting and design of LNG facilities. It must be stressed that although the approach for obtaining and reporting these data is similar to that for nuclear plants, LNG plants will be evaluated by FERC using the criteria for LNG facilities in the DoT and NFPA safety standards.

## 1.3 DEFINITIONS

The following generally accepted definitions provide the general meaning of some of the terms used in this report.

Applicant: Any person, firm, or corporation which files an application before the Federal Energy Regulatory Commission to construct, modify or operate LNG plants under the Commission's jurisdiction.

Category I: All structures, components and systems which perform a vital safety-related function such as containment of LNG and fire control.

Category II: All structures, components, and systems, other than those in Category I, which are required to maintain continued safe plant operation.

Category III: Facilities which are essential operational support facilities not required for operation, shutdown, or maintenance of a safe shutdown condition.

Component: Any part, or system of parts functioning as a unit, including but not limited to, piping, processing equipment, containers, control devices, impounding systems, lighting, security devices, fire control equipment, and communications equipment, whose integrity or reliability is necessary to maintain safety in controlling, processing, or containing a hazardous fluid.

Container: A component other than piping that contains a hazardous fluid.

Dike: The perimeter of an impounding space forming a barrier to prevent liquid from flowing in an unintended direction.

Effective frequency range: The frequency content of an accelerogram of interest in the range of frequencies of the LNG plant's structures, components and systems.

Fault: A fracture zone within the earth's crust along which displacement of the two sides relative to one another has occurred parallel to the fracture.

Fault length: The length of a continuous zone of faulting which can be expected to act as a single structure, regardless of the lack of continuity of surface faulting.

Hazardous fluid: LNG or a flammable, toxic, or corrosive gas or liquid.

Holocene: The Holocene or Recent epoch of geologic time, extending from the present to about 10,000 years before the present.

Impounding space: A volume formed by dikes and floors designed to confine a spill of hazardous liquid.

Impounding system: An impounding space as well as dikes and floors designed to conduct the flow of spilled hazardous liquids to an impounding space.

Intensity: A numerical index describing the effects of an earthquake on the earth's surface, on man, and on structures built by him. The scale in common use in the United States today is the Modified Mercalli Scale of 1931 with intensity values indicated by Roman numerals from I to XII.

Internal Category I structure: Structures enclosed by a container and assigned to Category I.

Magnitude: The numerical value on a Richter scale and is a measure of the size of an earthquake as it is related to the energy released in the form of seismic waves.

Most critical ground motion (MCGM): The ground vibration, usually expressed in units of "g", the acceleration of earth's gravity, which has a mean recurrence interval at the LNG plant site of 10,000 years. It may be equated to that vibration resulting from the SSE.

Operating basis earthquake (OBE): Defined probabilistically as producing ground motions with a mean recurrence interval of 475 years, or deterministically as producing ground motions of at least one-half those for the SSE.

Quaternary: The Quaternary period of geologic time, extending from the present to about 2 million years before the present. It includes the Holocene and Pleistocene epochs.

Response spectrum: A plot of the maximum responses (acceleration, velocity or displacement) of a family of idealized single-degree-of-freedom damped oscillators against natural frequencies (or periods) of the oscillators to a specified vibratory motion input at their supports.

Safe shutdown earthquake (SSE): Defined probabilistically as producing ground motions with a mean recurrence interval of 10,000 years (the MCGM) or, in regions where lack of geological data makes uncertainties difficult to quantify, deterministically as producing the MCGM at the site based upon the seismology, geology, and seismic and geologic history of the site and region.

Safety-related slopes/safety-related embankments: Any slope or embankment that could affect the stability or integrity of a Category I structure.

Soil liquefaction: A sudden large decrease of the shearing resistance of a cohesionless soil, caused by a collapse of the soil structure by shock or strain (e.g., by an earthquake), and associated with a sudden, temporary increase in pore fluid pressure. The soil temporarily becomes a fluid.

Storage tank: A container for storing a hazardous fluid, including an underground cavern.

Surface faulting: Differential ground displacement at or within about 50 feet of the surface caused by movement along a fault. It may or may not be associated with an earthquake on that fault.

Tectonic province: A region characterized by similar tectonic structures and/or history distinct from adjacent regions.

Tectonic structure: A large scale dislocation or distortion formed within the earth's crust as a result of forces within the earth.

Zone: The area designated by the numbers 0, 1, 2, 3 or 4 on the Uniform Building Code, Seismic Risk Map of the United States.

# 2. LNG STANDARDS

## 2.1 INTRODUCTION

This chapter summarizes the site investigation and seismic design requirements of the DoT and NFPA safety standards. Basically, the two standards apply to the same types of facilities, although the NFPA standard does not apply to frozen ground containers. The requirements are summarized in the abbreviated flow chart in figure 1 and are described in more detail in sections 2.1.1 and 2.1.2. The FERC staff would like applicants' reports to address the requirements of both standards and, in general, will require use of the more stringent standard.

### 2.1.1 DoT Safety Standard

The Federal Safety Standards for LNG facilities are contained in the DoT Standard, 49 CFR 193. The Standard applies to all LNG facilities, including all of those under the jurisdiction of the FERC. The Standard defines two types of containers, those requiring specific site investigations prior to seismic design and a special category of containers that do not require specific site investigations. Referring to Item A in figure 1, the DoT standard defines a special category container as one that is shop fabricated, has a capacity of less than 70,000 gallons, and is installed within two feet of the ground. Such a container does not require a site investigation and may be designed using simplified lateral forces that are determined in accordance with the appropriate zone of the Uniform Building Code (UBC) and assuming a vertical force equal to the total UBC lateral force. The tank is then designed and built to withstand those simplified lateral forces without loss of structural or functional integrity.

A site investigation is required for tanks that do not meet the special category requirements as shown in Item B, figure 1. The site must be examined to determine if there is potential for surface faulting or liquefaction in all UBC zones.

Except by special approval by the Director of the Materials Transportation Bureau of DoT, an LNG storage tank or its impounding system may not be located at a site where:

1. The specific local geologic and seismic data base is sufficient to predict future differential displacement beneath the tank and dike area, but displacement not exceeding 30 inches cannot be assured with a high level of confidence.

2. The specific local geologic and seismic data base is not sufficient to predict future differential displacement beneath the tank and dike area, and the cumulative displacement of a Quaternary fault within one mile of the tank foundation exceeds 60 inches.

3. The potential for soil liquefaction cannot be accommodated by design and construction.

If there is no potential for surface faulting or liquefaction, and if the UBC zone is 0 or 1, then the facility may be designed according to the simplified lateral force method used for special category containers, otherwise ground motions must be determined based on a specific site investigation. The design is to be based on foundation forces resulting from the most critical ground motion defined as having a yearly probability of less than $10^{-4}$. If the estimated design horizontal acceleration based on the site study exceeds 0.8 g at the tank or dike foundation, then the site will not be allowed except by special approval by DoT. For accelerations less than 0.8 g, the design forces are determined (Item C) and the facility must be designed (Item D) and built to withstand without loss of structural or functional integrity the forces that result from the design acceleration.

### 2.1.2 NFPA Safety Standard

The NFPA Standard also defines a special category container (Item A, figure 1) that may be designed by a simplified procedure. This container is one that is shop built and meets the ASME code. For the special category of container the force level is defined according to a zone map included in the NFPA Standard.

This map, which includes four zones, is different from the one used by the UBC. It defines a mean acceleration level within each zone that has a probability of exceedance of 10 percent over a 50 year period. If the special container is located in zone 0 to zone 3, then simplified forces (Item C, figure 1) based upon the accelerations stated to occur in a specific zone may be used. If the container is located in zone 4, it is treated no differently than a container that does not meet the special requirements.

Facilities using non-special containers require the same type of site investigation in all zones within the U.S. (Item B, figure 1). Based upon the investigation, ground motions and design forces (Item C, figure 1) are determined and the design (Item D, figure 1) is conducted. Note that the NFPA document does not have the special exclusions identified by DoT.

The design is based on ground motions resulting from two earthquakes; the safe shutdown earthquake (SSE) and the operating basis earthquake (OBE). These design earthquakes are defined by the NFPA safety standard as those which produce ground motions with a mean recurrence interval of 10,000 and 475 years, respectively. Where the geological data do not support a probabilistic approach, the SSE creates the maximum credible ground motion and the OBE value is taken as one half the SSE values.

These ground motions are used in the design of the LNG container and its impounding system, system components required to isolate the LNG container and maintain it in a safe shutdown condition, and the fire protection system. Note that this two level earthquake design differs from the single level identified by the DoT standard.

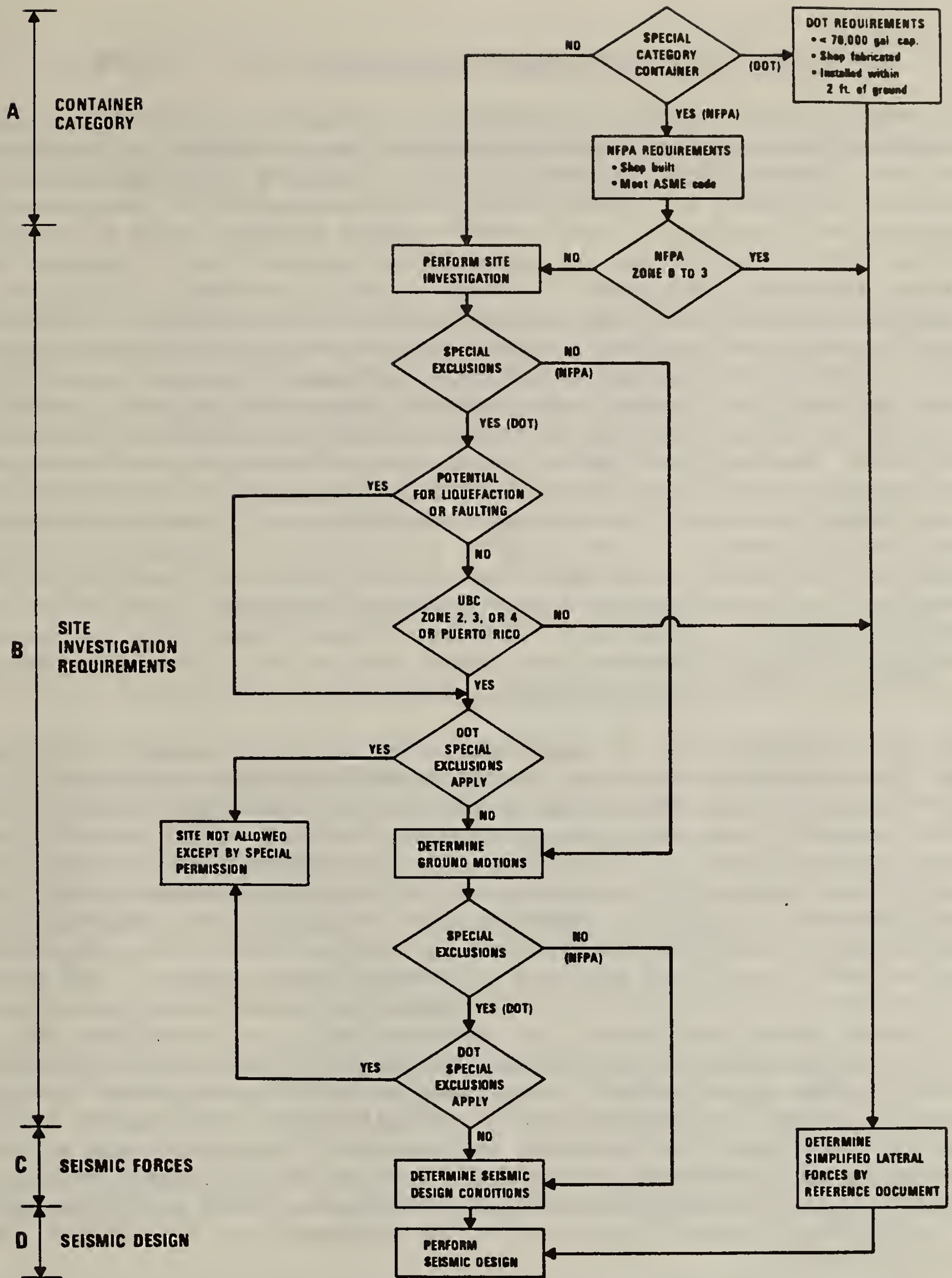


Figure 1. Flow chart of DoT and NFPA Safety Standards

## 2.2 USE OF THE DOT AND NFPA SAFETY STANDARDS

In order to effectively use two design earthquakes, structures, components, equipment, systems, and their foundations must be placed in categories depending on their importance to system operation. Category I includes all LNG facilities defined in Subpart B of 49 CFR 193. They are structures, components, and systems which perform a vital safety-related function (such as containment of LNG and fire control) and are expected to maintain their structural and functional integrity during and following an SSE. Category I facilities must maintain their operational function during and following an OBE. Category II facilities are structures, components, and systems, other than those in Category I, which are required to maintain continued safe plant operation. They must maintain their operational function during and following an OBE with certain levels of inelastic deformation permitted. However, safety-related functions not capable of being taken over by Category I facilities should not be impaired during or following an SSE and interaction of Category II facilities with Category I facilities during or following an SSE must not impair the required performance of the Category I facilities. Category III facilities, which are essential operational support facilities not required for operation, shutdown, or maintenance of a safe shutdown condition of the plant may be designed by the UBC approach. However, failure (operational or structural) of Category III facilities must not impair the ability of Category I or II facilities to perform as required above.

The UBC approach which is essentially that used for Category III structures, has been developed for use in design of building-type structures. It is a static analysis approach based on forces which are significantly less than those actually seen during an earthquake. Because of the level of forces involved in the design, it is presumed that some structural damage will occur and that structures will be designed and detailed to tolerate this damage without subsequent collapse. Structures are expected to accommodate the stronger earthquake by yielding and cracking the various structural elements as well as by the added resistance provided by nonstructural elements. The overall philosophy of the UBC is felt to be justified based on the remote possibility of damage during the life of the structure due to an earthquake and, by the large expense required to make the building earthquake resistant and remain elastic with non structural damage when it would be subjected to a large earthquake. It has long been recognized in California, for example, that special seismic provisions are necessary for important structures such as schools, hospitals and communication centers. Because of this approach there can be no guarantee that facilities designed in this manner will satisfy criteria similar to structures designed according to the Category I or Category II classification.

Classification of LNG structures, components, and systems may be found in Appendix B.

## 3. CONTENTS OF APPLICANTS' REPORT

Each applicants' report should contain the following sections with the identified information. The preface "3" for this section has been omitted for simplicity in identifying the section numbers in the applicants' report. Section titles with the "3" omitted are in italics.

### *1 PLANT DESCRIPTION*

The plant description should include a brief discussion of the principal design criteria, operating characteristics, and safety considerations for the engineered safety features and emergency systems; the instrumentation, control, and electrical systems; and the LNG handling and storage systems. The general arrangement of major structures and equipment should be indicated by the use of plan and elevation drawings in sufficient number and detail to provide a reasonable understanding of the general layout of the plant. Those features of the plant likely to be of special interest because of their relationship to safety should be identified.

### *2 SUMMARY OF SITE INVESTIGATION AND FACILITY DESIGN STATUS*

The applicant should document the current status of the site evaluation study. Additional planned investigations should also be described.

The applicant shall document the current design status of the facility. That is, the applicant should identify the design stage between conceptual design to final design. The applicant should also identify what level of computations have been performed to arrive at the current design stage and what studies, data gathering, calculations and documentations remain to be done. Such items as unusual site characteristics, solutions to particularly difficult engineering problems, and significant extrapolation in technology represented by the design should be highlighted.

### *3 REQUIREMENTS FOR FURTHER TECHNICAL INFORMATION*

Identify, describe, and discuss those safety features or components for which further technical information is required in support of the issuance of a certificate, but which has not been supplied. This information should include:

1. Development programs that will be required to determine the adequacy of a new design and those that will be used to demonstrate the margin of conservatism of a proven design.

2. Describe the specific technical information that must be obtained to demonstrate acceptable resolution of the problems.

3. Provide a schedule of completion of the program as related to the projected startup date of the proposed plant.

## 4 GEOLOGY, SEISMOLOGY, AND GEOTECHNICAL ENGINEERING SITE EVALUATION

This section of the applicant's report should provide information regarding the seismic and geologic characteristics of the site and the region surrounding the site. "Liquefied Natural Gas Facilities: Federal Safety Standards, 49 CFR Part 193" gives the principal seismic and geologic considerations that guide the staff in its evaluation of the acceptability of sites and seismic design bases.

This section should include, but not necessarily be limited to, the information discussed below. Include a brief description of the site(s), the investigations performed, results of investigations, conclusions, and a statement as to who did the work.* The required investigations should closely follow the outline for presenting the information as described below.

### 4.1 BASIC GEOLOGIC AND SEISMIC INFORMATION

Basic geologic and seismic information is required throughout the following sections to provide a basis for evaluation. In some cases, this information is germane to more than one section. The information may be presented under this section or as an appendix, provided adequate cross-references are made in the appropriate sections.

Information obtained from published reports, maps, private communications, or other sources should be referenced. Information from surveys, geophysical investigations, borings, trenches, or other investigations should be adequately documented by descriptions of techniques, graphic logs, photographs, laboratory results, identification of principal investigators, and other data necessary to assess the adequacy of the information.

#### 4.1.1 Regional Geology

Discuss all geologic, seismic, and manmade hazards within the site region and relate them to the regional physiography, tectonic structures and tectonic provinces, geomorphology, stratigraphy, lithology, and geologic and structural history, and geochronology. The above information should be discussed, documented by appropriate references, and illustrated by a regional physiographic map, geologic maps of the surface and subsurface, isopach maps, regional gravity and magnetic maps, stratigraphic sections, tectonic and structure maps, fault maps, a site topographic map, a map showing areas of mineral and hydrocarbon extraction, boring logs, aerial photographs, and any maps needed to illustrate such hazards as subsidence, cavernous or karst terrain, irregular weathering conditions, and landslide potential.

The relationship between the regional and the site physiography should be discussed. A regional physiographic map showing the site location should be

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* The applicant is referred to Appendix A to 10 CFR Part 100 entitled "Seismic and Geologic Siting Criteria for Nuclear Power Plants" for useful information regarding site investigations (as applicable to LNG facilities).

included. Identify and describe tectonic structures such as folds, faults, basins, and domes underlying the region surrounding the site, and include a discussion of their geologic history. A regional tectonic map showing the structures of significance to the site should be provided. The detailed analyses of faults to determine their capacity for generating ground motions at the site and to determine the potential for surface faulting should be included in sections 4.2 and 4.3, respectively.

The lithologic, stratigraphic, and structural geologic conditions of the region surrounding the site should be described and related to its geologic history. Provide geologic profiles showing the relationship of the regional and local geology to the site location. The geologic province within which the site is located and the relation to other geologic provinces within 100 miles of the site should be indicated. Regional geologic maps indicating the site location and showing both surface and bedrock geology should also be included.

### *4.1.2 Site Geology*

Material on site geology included in this section may be cross-referenced in section 4.4. The site physiography and local landforms should be described and the relationship between the regional and site physiography should be discussed. A site topographic map showing the locations of the principal plant facilities should be included. Describe the configuration of the land forms and relate the history of geologic changes. Areas of actual or potential landsliding, subsidence, uplift, or collapse resulting from natural features such as tectonic depressions and cavernous or karst terrains that are significant to the site should be evaluated.

The detailed lithologic and stratigraphic conditions of the site and the relationship to the regional stratigraphy should be described. The thicknesses, physical characteristics, origin, and degree of consolidation of each lithologic unit should also be described, including a local stratigraphic column. Furnish summary logs of borings and excavations such as trenches used in the geologic evaluation. Boring logs included in section 4.4 may be referenced.

A detailed discussion of the structural geology in the vicinity of the site should be provided. Include in the discussion the relationship of site structure to regional tectonics, with particular attention to specific structural units of significance to the site such as folds, faults, synclines, anticlines, domes, and basins. Provide a large-scale structural geology map (scale no smaller than 1:5,000) of the site showing bedrock surface contours and including the locations of Category I structures. A large-scale geologic map (1:24,000) of the region within 5 miles of the site that shows surface geology and that includes the locations of major structures of the LNG plant, including all Category I structures, should also be furnished. Areas of bedrock outcrop from which geologic interpretation has been extrapolated should be distinguished from areas in which bedrock is not exposed at the surface. When the interpretation differs substantially from the published geologic literature on the area, the differences should be noted and documentation for the new conclusions presented.

The geologic history of the site should be discussed and related to the regional geologic history. Include an evaluation from an engineering-geology standpoint of the local geologic features that affect the plant structures. Geologic conditions underlying all Category I structures, dams, dikes, and pipelines should be described in detail. The dynamic behavior of the site during prior earthquakes should be described. Deformational zones such as shears, joints, fractures, and folds, or combinations of these features should be identified and evaluated relative to structural foundations. Describe and evaluate zones of alteration or irregular weathering profiles, zones of structural weakness, unrelieved residual stresses in bedrock, and all rocks or soils that might be unstable because of their mineralogy or unstable physical or chemical properties. The effects of man's activities in the area of the site should be evaluated. For example, withdrawal or addition of subsurface fluids or mineral extraction.

Site groundwater conditions should be described.

### 4.2 VIBRATORY GROUND MOTION

This section is directed toward establishing the seismic design basis for vibratory ground motion. The presentation should be aimed at (1) determining the SSE and the OBE for the site and (2) specifying the vibratory ground motion corresponding to each of these events. Determination of the SSE and the OBE should be based on the identification of tectonic provinces or active geologic structures with which earthquake activity in the region can be associated. The design vibratory ground motion for the SSE and OBE should then be determined by assessing the effects at the site of the SSE and OBE associated with the identified provinces or structures.

The presentation in the report should proceed from discussions of the regional seismicity, geologic structures, and tectonic activity to a determination of the relation between seismicity and geologic structures. The earthquake generating potential of tectonic provinces and any active structures should be identified. Finally, the ground motion that would result at the site from the maximum potential earthquakes associated with each tectonic province or geologic structure should be assessed considering any site amplification effects. The results should be used to establish the vibratory ground motion design spectrum.

Information should be presented to describe how the design basis for vibratory ground motion was determined. The following specific information and determinations should also be included, as needed, to clearly establish the design basis for vibratory ground motion.

#### 4.2.1 Seismicity

A complete list of all historically reported earthquakes that could have reasonably affected the region surrounding the site should be provided. The listing should include all earthquakes of Modified Mercalli Intensity greater than IV or magnitude greater than 3.0 that have been reported in all tectonic provinces, any part of which is within a distance that could affect the site response significantly. This account should be augmented by a regional-scale map showing all listed earthquake epicenters and, in areas of high seismicity,

by a larger-scale map showing earthquake epicenters within 50 miles[1] of the site. The following information describing each earthquake should be provided whenever it is available: epicenter coordinates, depth of focus, origin time, highest intensity, isoseismal maps (if the site intensity was at least IV), magnitude, seismic moment, source mechanism, source dimensions, source rise time, rupture velocity, total dislocation, fractional stress drop, any strong-motion recordings relevant to a determination of the MCGM or design response spectra, and identification of references from which the specified information was obtained. In addition, any earthquake-induced geologic hazards (e.g., liquefaction, landsliding, landspreading, or lurching) that have been reported on or within 5 miles of the site should be described in detail, including the level of strong motion that induced failure and the properties of the materials involved.

### *4.2.2 Geologic Structures and Tectonic Activity*

Identify the regional geologic structures and tectonic activity that are significant in determining regional earthquake potential. All tectonic provinces any part of which occurs within 100 miles[1] of the site should be identified. The identification should include a description of those characteristics of geologic structure, tectonic history, present and past stress regimes, and seismicity that distinguish the various tectonic provinces and particular areas within those provinces where historical earthquakes have occurred. Alternative models of regional tectonic activity from available literature sources should be discussed. The discussion in this section should be augmented by a regional-scale map showing the tectonic provinces, earthquake epicenters, the locations of geologic structures and other features that characterize the provinces, and the locations of any Quaternary faults.

### *4.2.3 Correlation of Earthquake Activity with Geologic Structures or Tectonic Provinces*

Provide a correlation between epicenters or regions of highest intensity of historically reported earthquakes and geologic structures or tectonic provinces. Whenever an earthquake epicenter or concentration of earthquake epicenters have occurred within reasonable proximity to geologic structures, the rationale for the association should be developed. This discussion should include identification of the methods used to locate the earthquake epicenters and an estimate of their accuracy and should provide a detailed account that compares and contrasts the geologic structure involved in the earthquake activity with other areas within the tectonic province. When an earthquake epicenter cannot

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[1] The 50 and 100 mile figures in *4.2.1* and *4.2.2* respectively are approximate distances to consider the effects of earthquakes at the site and are suggested as starting points. For example, perhaps 400 miles should be used in some areas in the midwest, taking into account the New Madrid area and the effects of long period waves on a structure. Whereas, in the Western U.S., a much shorter distance would be applicable as a medium, local earthquake with high frequency components may govern design.

be reasonably correlated with geologic structures, the epicenter should be discussed in relation to tectonic provinces. Subdivision of tectonic provinces should be supported on the basis of evaluations that consider, but should not be limited to, detailed seismicity studies, tectonic flux measurements, contrasting structural fabric, differences in geologic history, and differences in stress regime.

#### *4.2.4 Maximum Earthquake Potential*

The largest earthquake associated with each geologic structure or tectonic province should be identified. Where the earthquakes are associated with a geologic structure, the largest earthquake that could occur on that structure should be evaluated based on considerations such as the nature of faulting, fault length, fault displacement, and earthquake history. Where the earthquakes are associated with a tectonic province within 100 miles of the site, the largest historical earthquakes within the province should be identified and, whenever reasonable, the return period for the earthquakes should be estimated.

Ground motion at the site should be determined assuming seismic energy transmission effects are constant over the region, unless there is reason to believe directional effects might increase the design ground motion, and assuming the largest earthquake associated with each geologic structure or with each tectonic province occurs at the point of closest approach of that structure or province to the site. The set of conditions describing the occurrence of the potential earthquake that would produce the largest vibratory ground motion at the site should be defined. If different potential earthquakes would produce the maximum ground motion in different frequency bands, the conditions describing all such earthquakes should be specified. The description of the potential earthquake occurrences should include the maximum intensity or magnitude and distance from the assumed location of the potential earthquake to the site.

#### *4.2.5 Seismic Wave Transmission Characteristics of the Site*

The following material properties should be determined for each stratum under the site that influences the response of the site: seismic compressional and shear velocities, bulk densities, soil properties and classification, shear modulus and damping and their variation with strain level, and water table elevation and its variation. The methods used to determine these properties should be described. For each set of conditions describing the occurrence of the maximum potential earthquakes, determined in section 4.2.4, the types of seismic waves producing the maximum ground motion and the significant frequencies at the site should be determined. For each set of conditions, an analysis should be performed to determine the effects of transmission in the site material for the identified seismic wave types in the significant frequency bands.

#### 4.2.6 *Safe Shutdown Earthquake, SSE*

The acceleration at the ground surface, the effective frequency range, and the duration corresponding to each maximum potential earthquake should be determined. Where the earthquake has been associated with a geologic structure, the acceleration should be determined using a relation between acceleration, magnitude, or fault length, earthquake history and other geologic information, and the distance from that structure. Where the earthquake has been associated with a tectonic province, the acceleration should be determined using appropriate relations between acceleration, intensity, epicentral intensity, and distance. Available ground motion time histories from earthquakes of comparable magnitude, epicentral distance, and acceleration level should be presented. The spectral content from each maximum potential earthquake should be described based on consideration of the available ground motion time histories and regional characteristics of seismic wave transmission. The dominant frequency associated with the peak acceleration should be determined either from analysis of ground motion time histories or by inference from descriptions of earthquake phenomenology, damage reports, and regional characteristics of seismic wave transmission. Design response spectra corresponding to the SSE should be defined and their conservatism assessed by comparing them to the ground motion expected from the potential earthquakes.

#### 4.2.7 *Operating Basis Earthquake, OBE*

The vibratory ground motion for the Operating Basis Earthquake should be described and the probability of exceeding the OBE during the operating life of the plant should be determined.

### 4.3 *SURFACE FAULTING*

Information should be provided to determine whether a potential for surface faulting exists at the site. Special attention should be paid to potential surface faulting with a yearly probability of occurrence of $10^{-4}$ or greater. The following specific information and determinations should also be included to the extent necessary to clearly establish zones requiring detailed faulting investigation. Information presented in section *4.1* may be cross-referenced and need not be repeated. Measures to avoid or accommodate any potential faulting should be described in section *5*.

#### 4.3.1 *Geologic Conditions of the Site*

The lithologic, stratigraphic, and structural geologic conditions of the site and the area surrounding the site, including its geologic history, should be described. Site and regional geologic maps and profiles illustrating the surface and bedrock geology, structural geology, topography, and the relationship of the safety-related foundations of the LNG plant to these features should be included.

*4.3.2 Investigation of Quaternary Faults*

Identified faults, any part of which is within 5 miles of the site, should be investigated in sufficient detail and using geological and geophysical techniques of sufficient sensitivity to demonstrate the age of most recent movement on each. The type and extent of investigation varies from one geologic province to another and depends on site-specific conditions.

For Quaternary faults, any part of which is within 5 miles of the site, determine: the length of the fault; the relationship to regional tectonic structures; the nature, amount, and geologic displacement along the fault; and outer limits of the fault zone.

*4.3.3 Determination of Active Faults*

Determine the geologic evidence of fault offset at or near the ground surface at or near the site. Any topographic or photo linears and Landsat (ERTS) linears identified as part of this study should be discussed.

List all historically reported earthquakes that can be reasonably associated with faults, any part of which is within 5 miles of the site. A plot of earthquake epicenters superimposed on a map showing the local tectonic structures should be provided.

The structure and genetic relationship between site area faulting and regional tectonic framework should be discussed. In regions of active tectonism, any detailed geologic and geophysical investigations conducted to demonstrate the structural relationships of site area faults with regional faults known to be seismically active should be discussed.

*4.3.4 Detailed Faulting Investigation*

A detailed faulting investigation should be conducted within one mile of the storage tank(s) foundation(s) and, as necessary, along any active faults identified under section *4.3.3* which may reasonably have a potential for affecting faulting on the site or provide significant information concerning such faulting. This investigation should be in sufficient detail to determine the potential for faulting and the magnitude of displacement that could be experienced by the safety-related facilities of the plant. The report of the investigation should be coordinated with the investigation and report under section *4.3.2* and *4.3.3* and should include information in the form of boring logs, detailed geologic maps, geophysical data, maps and logs of trenches, remote sensing data, and seismic refraction and reflection data. If faulting exists, it should be defined as to its attitudes, orientations, width of shear zone, amount and sense of movement, and age of movements. Site surface and subsurface investigations to determine the absence of faulting should be reported, including information on the detail and areal extent of the investigation.

## 4.4 STABILITY OF SUBSURFACE MATERIALS AND FOUNDATIONS

Information should be presented that thoroughly defines the conditions and engineering properties of both soil and/or rock supporting LNG plant foundations. The stability of the soils and rock under plant structures should be evaluated both for static and dynamic loading conditions (including an evaluation of the ability of these materials to perform their support function without incurring unexpected or excessive subsidence and settlement due to their long-term consolidation under load or to their response to natural phenomena). Both the Operating Basis and Safe Shutdown Earthquakes should be used in the dynamic stability evaluation. An evaluation of site conditions and geological features that may affect LNG plant structures or their foundations should be presented. Information presented in other sections should be cross-referenced rather than repeated.

### 4.4.1 Geologic Features

Describe geologic features, including the following:

1. Areas of actual or potential surface or subsurface subsidence, uplift, or collapse and the causes of these conditions,

2. Previous loading history of the foundation materials, i.e., history of deposition and erosion, groundwater levels, and glacial or other preloading influences on the soil,

3. Rock jointing pattern and distribution, depth of weathering, zones of alteration or irregular weathering, and zones of structural weakness composed of crushed or disturbed materials such as slickensides, shears, joints, fractures, faults, folds, or a combination of these features. Especially note seams and lenses of weak materials such as clays and weathered shales,

4. Unrelieved residual stresses in bedrock, and

5. Rocks or soils that may be hazardous, or may become hazardous, to the plant because of their lack of consolidation or induration, inhomogeneity, variability, high water content, solubility, or undesirable response to natural or induced site conditions.

### 4.4.2 Properties of Subsurface Materials

Describe in detail the static and dynamic engineering properties of the materials underlying the site. The classification and engineering properties of soils and rocks should be determined by testing techniques defined by accepted standards such as those of the American Society of Civil Engineers, American Society for Testing and Materials, and American Association of State Highway and Transportation Officials or in manuals of practice issued by the Army Corps of Engineers and the Bureau of Reclamation. The determination of dynamic or special engineering properties should be by accepted state-of-the-art

methods such as those described in professional geotechnical journals. Reported properties of foundation materials should be supported by field and laboratory test records. Furnish data to justify the selection of design parameters. These data should be sufficient to permit the staff to make an independent interpretation and evaluation of design parameters. Furnish summaries of the physical (static and dynamic), index, and chemical properties of materials. Information provided should include grain-size distribution (graphic representation), consolidation data, mineralogy, natural moisture content, Atterberg limits, unit weights, shear strength, relative density, overconsolidation ratio, ion exchange capacity, sensitivity, swelling, shear modulus, damping, Poisson's ratio, bulk modulus, cyclic strength, and seismic wave velocities.

*4.4.3 Exploration*

Discuss the type, quantity, extent, and purpose of all explorations. Provide plot plans that graphically show the location of all site explorations such as borings, trenches, borrow pits, seismic lines, piezometers, wells, geologic profiles, and the limits of required construction excavations. The locations of the safety-related facilities should be superimposed on the plot plan. Also, furnish selected geologic sections and profiles that indicate the location of borings and other site exploration features, groundwater elevations, and final foundation grades. The location of safety-related foundations should be superimposed on these sections and profiles.

Logs of all borings and test pits should be provided. Furnish logs and maps of exploratory trenches and geologic maps and photographs of the excavations for the facilities of the LNG plant.

*4.4.4 Geophysical Surveys*

Results of compressional and shear wave velocity surveys performed to evaluate the occurrence and characteristics of the foundation soils and rocks should be provided in tables and profiles. Discuss other geophysical methods used to define foundation conditions.

*4.4.5 Excavations and Backfill*

The following data concerning excavation, backfill, and earthwork at the site should be discussed:

1. The extent (horizontally and vertically) of all Category I excavations, fills, and slopes. The locations and limits of excavations, fills, and backfills should be shown on plot plans and on geologic sections and profiles,

2. The dewatering and excavation methods to be used. Evaluate how these will affect the quality and condition of foundation materials. Discuss the need and proposed measures for foundation protection and treatment after excavation. Also discuss proposed quality control and quality assurance programs related to foundation excavation, and

subsequent protection and treatment. Discuss measures to monitor foundation rebound and heave, and

3. The sources and quantities of backfill and borrow. Describe exploration and laboratory studies and the static and dynamic engineering properties of these materials in the same fashion as described in sections *4.4.2* and *4.4.3*. Provide the plans for field test fills and identify the material and placement specifications proposed. Include grain size bands, moisture control, and compaction requirements. Results of test fills should be included. Discuss measures to monitor foundation settlement.

*4.4.6 Groundwater Conditions*

The analysis of groundwater at the site should include the following points:

1. A discussion of groundwater conditions relative to the stability of the safety-related LNG plant facilities,

2. A discussion of design criteria for the control of groundwater levels or collection and control of seepage,

3. Requirements for dewatering during construction and a discussion of how dewatering will be accomplished,

4. Records of field and laboratory permeability tests,

5. History of groundwater fluctuations, including those due to flooding, and projected variances in the groundwater levels during the life of the plant,

6. Information related to the periodic monitoring of local wells and piezometers,

7. Direction of groundwater flow, gradients, and velocities, and

8. Discussion of or reference to the groundwater monitoring program during the life of the plant to assess the potential for subsidence.

*4.4.7 Response of Soil and Rock to Dynamic Loading*

Furnish analyses of the responses of the soil and rock to dynamic and seismic loading conditions. Discuss the testing performed and test results. Provide the basis for selected design values used for dynamic response analyses. Justify the methods of analyses used and indicate the results of analyses. Identify computer programs used and provide abstracts. Soil-structure interaction analyses should be described in this section or cross-referenced from section *4.2.4*. Buried pipelines and earthworks should also be included in this section.

#### 4.4.8 *Liquefaction Potential*

If the foundation materials at the site adjacent to and under safety-related structures are saturated sandy or silty soils or soils that have a potential for becoming saturated, an appropriate state-of-the-art analysis of the potential for liquefaction occurring at the site should be provided. The method of analysis should be determined on the basis of actual site conditions, the properties of the plant facilities, and the earthquake and seismic design requirement.

#### 4.4.9 *Earthquake Design Basis*

Justify the selection of earthquakes for liquefaction and seismic response analysis of earthworks.

#### 4.4.10 *Static Stability*

The stability of all safety-related facilities should be analyzed for static loading conditions. Foundation rebound, settlement, differential settlement, and bearing capacity should be analyzed under the design loads of fills and plant facilities. A discussion and evaluation of lateral earth pressures and hydrostatic groundwater loads acting on plant facilities should be included in this section. Field and laboratory test results should be discussed. Design parameters used in stability analyses should be discussed and justified. Sufficient data and analyses should be provided so that the staff may make an independent interpretation and evaluation. Results of stability analyses should be presented.

#### 4.4.11 *Design Criteria*

Provide a brief discussion of the design criteria and methods of design used in the stability studies of all safety-related facilities. Identify required and computed factors of safety, assumptions, and conservatisms in each analysis. Provide references. Explain and verify computer analyses used.

#### 4.4.12 *Techniques to Improve Subsurface Conditions*

Discuss and provide specifications for measures to improve foundations such as grouting, dynamic consolidation, vibroflotation, dental work, rock bolting, and anchors. A verification program designed to permit a thorough evaluation of the effectiveness of foundation improvement measures should also be discussed.

#### 4.4.13 *Subsurface Instrumentation*

Instrumentation for the surveillance of foundations for safety-related structures should be presented in this section. Indicate the type, location, and purpose of each instrument and provide significant details of installation methods. Provide a schedule for installing and reading all proposed instruments and for the interpretation of the data obtained. Results and analyses should be presented.

## 4.5 STABILITY OF SLOPES

Information should be presented concerning the static and dynamic stability of all soil or rock slopes, both natural and man-made, the failure of which could adversely affect the safety of the LNG plant. This information should include a thorough evaluation of site conditions, geologic features, the engineering properties of the materials comprising the slope and its foundation. The stability of slopes should be evaluated using classic and contemporary methods of analyses. The evaluation should include, whenever possible, comparative field performance of similar slopes. All information related to defining site conditions, geologic features, the engineering properties of materials, and design criteria should be of the same scope as that provided under section 4.4. Cross-references may be used where appropriate. The stability evaluation of man-made slopes should include summary data and a discussion of construction procedures, record testing, and instrumentation monitoring to ensure high quality earthwork.

### 4.5.1 Slope Characteristics

Describe and illustrate slopes and related site features in detail. Provide a plan showing the limits of cuts, fills, and natural undisturbed slopes and show their relation and orientation relative to plant facilities. Benches, retaining walls, bulkheads, jetties, and slope protection should be clearly identified. Provide detailed cross sections and profiles of all slopes and their foundations. Discuss exploration programs and local geologic features. Describe the groundwater and seepage conditions that exist and those assumed for analysis purposes. The type, quantity, extent, and purpose of exploration should be described and the location of borings, test pits, and trenches should be shown on all drawings. Discuss sampling methods used. Identify material types and the static and dynamic engineering properties of the soil and rock materials comprising the slopes and their foundations. Identify the presence of any weak zones, such as seams or lenses of clay, mylonites, or potentially liquefiable materials. Discuss and present results of the field and laboratory testing programs and justify selected design strengths.

### 4.5.2 Design Criteria and Analyses

The design criteria for the stability and design of all safety-related and Category I slopes should be described. Valid static and dynamic analyses should be presented to demonstrate the reliable performance of these slopes throughout the lifetime of the plant. Describe the methods used for static and dynamic analysis and indicate reasons for selecting them. Indicate assumptions and design cases analyzed with computed factors of safety. Present the results of stability analyses in tables identifying design cases analyzed, strength assumptions for materials, and type of failure surface.

Assumed failure surfaces should be graphically shown on cross sections and appropriately identified on both the tables and sections. Explain and justify computer analyses; provide a brief description of computer programs used.

#### 4.5.3 *Logs of Borings*

Present the logs of borings, test pits and trenches that were completed for the evaluation of slopes, foundations, and borrow materials to be used for slopes.

Logs should indicate elevations, depths, soil and rock classification information, groundwater levels, exploration and sampling methods, recovery, RQD, and blow counts from standard penetration tests. Provide specific details of how the Standard Penetration Test was performed. Discuss drilling and sampling procedures and indicate where samples were taken on the logs.

#### 4.5.4 *Compacted Fill*

In this section, provide information related to material, placement, and compaction specifications for fill (soil and/or rock) required to construct slopes such as canal or channel slopes, breakwaters, and jetties. Planned construction procedures and control of earthworks should be thoroughly described. Information necessary is similar to that outlined in section 4.4.5. Quality control techniques and documentation should be discussed.

### 4.6 EMBANKMENTS AND DAMS

This section should include information related to the investigation, engineering design, proposed construction, and performance of all earth, rock, or earth and rock fill embankments used for plant flood protection. The format given below may be used for both Category I and safety-related embankments, the failure of which could threaten the public health and safety. The following information should be included: (1) the purpose and location of the embankment and appurtenant structures (e.g., spillways and outlet works), (2) specific geologic features of the site, (3) engineering properties of the bedrock and foundation and embankment soils, (4) design assumptions, data, analyses, and discussions on foundation treatment and embankment design, (5) any special construction requirements, and (6) proposed instrumentation and performance monitoring systems and programs. Embankment design studies should indicate an evaluation of the performance of the embankment based on the design input.

Embankment zone placement quantities, a comparison of embankment zone design placement requirements with a summary of field control test data results and a comparison of embankment shear strength design assumptions with a summary of record control shear strength test results should be tabulated.

The following drawings should be provided:

1. General plan with vicinity map,

2. Large-scale embankment plan with boring and instrumentation locations shown,

3. Geologic profile along embankment axis, control structure axis, and spillway axis,

4. Embankment cross sections with instrumentation shown,

5. Embankment details,

6. Embankment foundation excavation plan,

7. Embankment and foundation design shear strength test data graphic summaries with selected design values shown,

8. Embankment slope stability cross sections with design assumptions, critical failure planes, and factors of safety shown,

9. Embankment slope stability reevaluation, if necessary,

10. Embankment seepage control design with assumptions, section, and selected design shown,

11. Relief well profile with the quantities of flow measured at various depths in the relief well shown,

12. Plot of pool elevation versus total relief well discharge quantities,

13. Distribution of field control test locations. For each zone tested, plot a profile parallel to the axis with field control test data plotted at the locations sampled,

14. Instrumentation installation details, and

15. Interpretations of instrumentation data:

    a. Settlement profile or contour plan,

    b. Alignment profiles of measured movements,

    c. Embankment section with embankment and foundation pore pressure contours. It may be necessary to plot contour diagrams at various dates,

    d. Embankment sections showing phreatic surface through foundation, and

    e. Profile in relief well line showing well and piezometer locations and measured and design heads.

*4.6.1 General*

The purpose of the embankment, including natural and severe conditions under which it is to function, should be stated. Identify the reasons for selecting the proposed location within the site. General design features, including planned water control structures, should be discussed.

#### *4.6.2 Exploration*

Discuss exploration and the local geologic features of the proposed embankment site, and relate these features to the plant site in general. The type, quantity, extent, and purpose of the underground exploration program should be provided. Exploration and sampling methods used should be discussed.

#### *4.6.3 Foundation and Abutment Treatment*

Discuss the need for, and justify the selection of the types of foundation and abutment treatment such as grouting, cutoff trenches, and dental treatment. Evaluate and report the effectiveness of the completed foundation and abutment treatment programs. The areal extent and depth limits of treatment should be shown on plot plans. Discuss the construction procedures to be employed, and estimate the construction quantities involved.

#### *4.6.4 Embankment*

Present the general embankment features including height, slopes, zoning, material properties (including borrow and foundation), sources of materials, and location and usage of materials in the embankment. Slope protection design, material properties, and placement methods should be presented. Discuss consolidation testing results, embankment settlement, and overbuild.

Compaction test results on laboratory test specimens and on test fills in the field should be discussed, as well as field control to be specified for the foundation preparation and protection and also for placement of fill, including material requirements, placement conditions, moisture control, and compaction. Also, discuss protection required of fill surfaces and stock-piles during construction, compaction equipment to be used, and any special fill placement activities required. Document compliance with specifications related to foundation preparation and also with material specifications and fill placement requirements. Significant or unusual construction activities and problems should also be documented.

#### *4.6.5 Slope Stability*

For both the foundation and embankment materials, discuss the shear testing performed, shear test data results, selected design strength, reasons for selecting the method of slope stability analysis used, and the results of design cases analyzed for the embankment constructed.

#### *4.6.6 Seepage Control*

Exploration and testing performed to determine assumptions used for seepage analyses should be discussed. Present design assumptions, results of design analyses, and reasons for the seepage control design selected. Special construction requirements as well as activities related to the final construction of seepage control features should be discussed.

#### *4.6.7 Performance Monitoring*

The overall instrumentation plan and the purpose of each set of instruments should be discussed, as well as the different kinds of instruments, special instruments, and significant details for installation of instruments. Describe the program for periodic monitoring of instrumentation and periodic inspection of the embankment and appurtenant structures.

## 5 DESIGN OF LNG CONTAINMENT STRUCTURES, COMPONENTS, EQUIPMENT, AND SYSTEMS

This chapter of the applicant's report should identify, describe, and discuss the principal architectural and engineering design of those structures, components, equipment, and systems important to safety and operation.

Particular attention should be placed on providing a physical description of the storage tanks and impounding systems including plan and section views sufficient to define the primary structural aspects. The arrangement of the containment, particularly the relationship and interaction of each storage tank with its surrounding floor should be provided to establish the effect that the structures could have on the design boundary conditions.

If the bottom of the tank is steel and the surface is not continuous, the method of anchorage of the steel shell walls to the concrete base slab should be described. Other major structural attachments should also be described.

The loads used in the design of the containment should be specified. Loads encountered during normal plant storage operation and shut-down, including dead loads, live loads, thermal loads, etc., should be listed.

### 5.1 CONFORMANCE WITH DoT SAFETY STANDARDS

This section should briefly discuss how the applicant has complied with the seismic investigation and design requirements of the DoT "Liquefied Natural Gas Facilities; Federal Safety Standards," specified in 49 CFR Part 193. For each section of the standard, a summary should be provided to show how the principal design features meet the standard. Any exceptions to the standard should be identified and the justification for each exception should be discussed. In the discussion of each portion of the standard, the sections of the report where more detailed information is presented to demonstrate compliance with or exceptions to the standard should be referenced.

### 5.2 CLASSIFICATION OF LNG CONTAINMENT STRUCTURES, COMPONENTS, AND SYSTEMS

This section should list all Category I and II items. If only portions of structures and systems are Category I or II, they should be listed and, where necessary for clarity, the boundaries of the Category I or II portions should be shown on piping and instrumentation diagrams.

Classification of LNG structures, components and systems may be found in appendix B.

### 5.3 SEISMIC DESIGN

#### 5.3.1 Design Response Spectra

Design response spectra (Operating Basis Earthquake (OBE) and Safe Shutdown Earthquake (SSE)) should be provided. The basis for any response spectra

should be included.* The response spectra applied at the finished grade in the free field or at the various foundation locations of Category I structures should be provided.

*5.3.2 Design Time History*

For the time history analyses, the response spectra derived from the actual or synthetic earthquake time-motion records should be provided. A comparison of the response spectra obtained in the free field at the finished grade level and the foundation level (obtained from an appropriate time history at the base of the soil/structure interaction system) with the design response spectra should be submitted for each of the damping values to be used in the design of structures, systems, and components. Alternatively, if the design response spectra for the OBE and SSE are applied at the foundation levels of Category I or II structures in the free field, a comparison of the free-field response spectra at the foundation level (derived from an actual or synthetic time history) with the design response spectra should be provided for each of the damping values to be used in the design. The period intervals at which the spectral values were calculated should be identified.

*5.3.3 Critical Damping Values*

The specific percentage of critical damping values used for Category I or II structures, systems, and components and soil should be provided for both the OBE and SSE (e.g., damping values for the type of construction or fabrication such as prestressed concrete and welded pipe). The basis for any proposed damping values should be included.

*5.3.4 Supporting Media for Category I and II Structures*

A description of the supporting media for each Category I and II structure should be provided. Include in this description foundation embedment depth, depth of soil over bedrock, soil layering characteristics, width of the structural foundation, total structural height, and soil properties such as shear wave velocity, shear modulus, and density. This information is needed to permit evaluation of the suitability of using either a finite element or lumped spring approach for soil/structure interaction analysis, if necessary.

## 5.4 *SEISMIC SYSTEM ANALYSIS FOR CATEGORY I STRUCTURES*

*5.4.1 Seismic Analysis Methods*

The applicable methods of seismic analysis (e.g., modal analysis response spectra, modal analysis time history, equivalent static load) should be identified and described. Descriptions (sketches) of typical mathematical models

* One reference providing guidance for preparation of response spectra is U.S. NRC Regulatory Guide 1.60, entitled "Design Response Spectra for Seismic Design of Nuclear Power Plants."

used to determine the response should be provided. Indicate how the dynamic system analysis method includes in the model consideration of foundation torsion, rocking, and translation. The method chosen for selection of significant modes and adequate number of masses or degrees of freedom should be specified. The manner in which consideration is given in the seismic dynamic analysis to maximum relative displacement among supports should be indicated. In addition, other significant effects that are accounted for in the seismic analysis (e.g., hydrodynamic effects and nonlinear response) should be indicated. If tests or empirical methods are used in lieu of analysis, the testing procedure, load levels, and acceptance bases should also be provided.

### 5.4.2 *Natural Frequencies and Response Modes*

The significant natural frequencies and response modes determined by seismic system analyses should be provided for Category I structures. In addition, the response spectra at critical Category I elevations and points of support should be specified.

### 5.4.3 *Procedure Used for Modeling*

The criteria and procedures used for modeling in the seismic system analyses should be provided. Include the criteria and bases used to determine whether a component or structure should be analyzed as part of a system analysis or independently as a subsystem.

### 5.4.4 *Soil/Structure Interaction*

As applicable, the methods of soil/structure interaction analysis used in the seismic system analysis and their bases should be provided. The following information should be included: (1) the extent of embedment, (2) the depth of soil over rock, and (3) the layering of the soil strata. If the finite element approach is used, the criteria for determining the location of the bottom boundary and side boundary should be specified. The procedure by which strain-dependent soil properties (e.g., damping and shear modulus) are incorporated in the analysis should also be specified. The material given in section 5.3.4 may be referenced in this section.

If lumped spring methods are used, the parameters used in the analysis should be discussed. Describe the procedures by which strain-dependent soil properties, layering, and variation of soil properties are incorporated into the analysis. The suitability of a lumped spring method used for the particular site conditions should also be discussed.

Any other methods used for soil/structure interaction analysis or the basis for not using soil/structure interaction analysis should be provided.

The procedures used to consider effects of adjacent structures on structural response in soil/structure interaction analysis should be provided.

### 5.4.5 *Development of Floor Response Spectra*

The procedures for developing floor response spectra considering the three components of earthquake motion should be described. If a modal response spectrum method of analysis is used to develop floor response spectra, the basis for its conservatism and equivalence to a time history method should be provided.

### 5.4.6 *Three Components of Earthquake Motion*

Identify the procedures for considering the three components of earthquake motion in determining the seismic response of structures, systems, and components.

### 5.4.7 *Combination of Modal Responses*

When a response spectra method is used, a description of the procedure for combining modal responses (shears, moments, stresses, deflections, and accelerations) should be provided.

### 5.4.8 *Interaction of Non-Category I Structures with Category I Structures*

Provide the design criteria used to account for the seismic motion of non-Category I structures or portions thereof in the seismic design of Category I structures or portions thereof. In addition, describe the design criteria that will be applied to ensure protection of Category I structures from the structural failure of non-Category I structures due to seismic effects.

### 5.4.9 *Effects of Parameter Variations on Floor Response Spectra*

The procedures that will be used to consider the effects of expected variations of structural properties, damping, soil properties, and soil/structure interaction on floor response spectra (e.g., peak width and period coordinates) and time histories should be described.

### 5.4.10 *Use of Constant Vertical Static Factors*

Where applicable, identify and justify the application of constant static factors as vertical response loads for the seismic design of Category I structures, systems, and components in lieu of a vertical seismic system dynamic analysis method.

### 5.4.11 *Method Used to Account for Torsional Effects*

The method used to consider the torsional effects in the seismic analysis of the Category I structures should be described. Where applicable, discuss and justify the use of static factors or any other approximate method in lieu of a combined vertical, horizontal, and torsional system dynamic analysis to account for torsional accelerations in the seismic design of Category I structures.

### 5.4.12 *Comparison of Responses*

For review where both modal response and time history methods are applied, the responses obtained from both methods at selected points in major Category I structures should be provided, together with a discussion of the comparative responses.

### 5.4.13 *Determination of Category I Structure Overturning Moments*

A description of the dynamic methods and procedures used to determine Category I structure overturning moments should be provided.

### 5.4.14 *Analysis Procedure for Damping*

The analysis procedure used to account for the damping in different elements of the model of a coupled system should be described.

## 5.5 *DESIGN AND ANALYSIS PROCEDURES*

The procedures that will be used in the design and analysis of all internal Category I structures should be described, including the assumptions made and the identification of boundary conditions. The expected behavior under load and the mechanisms for load transfer to these structures and then to the foundations should be provided. Computer programs that are utilized should be referenced to permit identification with published programs. Proprietary computer programs should be described to the maximum extent practical to establish the applicability of the program and the measures taken to validate the programs with solutions derived from other acceptable programs or with solutions of classical problems.

## 5.6 *STRUCTURAL ACCEPTANCE CRITERIA*

The acceptance criteria relating stresses, strains, gross deformations, and other parameters that identify quantitatively the margins of safety should be specified. The information provided should address the containment as an entire structure, and it should also address the margins of safety related to the major important local areas of the Category I structures important to the safety function. For each applicable load combination listed below, the allowable limits should be provided, as appropriate for stresses, strains, deformation, and factors of safety against structural failure. The extent of compliance with the various applicable codes should be presented. The load combinations to consider include but are not limited to:

1. Loads encountered during seasonal plant startup, including dead loads, live loads, thermal loads due to operating temperature, and hydrostatic loads.

2. Loads that would be sustained in the event of severe environmental conditions, including those induced by the Operating Basis Earthquake.

3. Loads that would be sustained in the event of extreme environmental conditions, including those that would be induced by the Safe Shutdown Earthquake.

## 5.7 *FOUNDATIONS*

This section should address foundations for all Category I structures constructed of materials other than soil for the purpose of transferring loads and forces to the basic supporting media. In particular, the information described below should be provided.

### 5.7.1 *Description of the Foundations*

This section should provide descriptive information, including plan and section views of each foundation, to define the primary structural aspects and elements relied upon to perform the foundation function. The relationship between adjacent foundations, including any separation provided and the reasons for such separation, should be described. In particular, the type of foundation and its structural characteristics should be discussed. The general arrangement of each foundation should be provided with emphasis on the methods of transferring horizontal shears, such as those seismically induced, to the foundation media. If shear keys are utilized for such purposes, the general arrangement of the keys should be included. If waterproofing membranes are utilized, their effect on the capability of the foundation to transfer shears should be discussed.

Information should be provided to adequately describe other types of foundation structures such as pile foundations, caisson foundations, retaining walls, abutments, and rock and soil anchorage systems.

### 5.7.2 *Applicable Codes, Standards, and Specifications*

This section should provide information, as applicable, on the foundations of all Category I structures.

### 5.7.3 *Loads and Load Combinations*

This section should provide information, as applicable, on the foundations of all Category I structures.

### 5.7.4 *Design and Analysis Procedures*

This section should provide information, as applicable, on the foundations of all Category I structures.

In particular, the assumptions made on boundary conditions and the methods by which lateral loads and forces and overturning moments, thereof, are transmitted from the structure to the foundation media should be discussed, along with the methods by which the effects of settlement are taken into consideration.

### 5.7.5 *Structural Acceptance Criteria*

This section should provide information applicable to foundations of all Category I structures.

In particular, the design limits imposed on the various parameters that serve to define the structural stability of each structure and its foundations should be indicated, including differential settlements and factors of safety against overturning and sliding.

### 5.7.6 *Materials, Quality Control, and Special Construction Techniques*

This section should provide information for the foundations of all Category I structures.

## 6 *MATERIALS, QUALITY CONTROL, AND SPECIAL CONSTRUCTION TECHNIQUES*

The applicant should provide quality assurance procedures for all Category I and II facilities in zones 2 through 4 including special inspection to assure the quality and performance of the seismic resisting systems.

A special inspector shall be employed by the applicant during construction to observe the work to be certain it conforms to the design drawings and specifications. The inspector shall furnish inspection reports to the engineer or architect of record, and other designated persons. All discrepancies shall be brought to the immediate attention of the contractor for correction, then, if uncorrected, to the engineer or architect of record.

The inspector shall submit a final signed report stating whether the work requiring special inspection was, to the best of his knowledge, in conformance with the approved plans and specifications and the applicable workmanship provisions.

## 7 *SEISMIC INSTRUMENTATION*

### 7.1 *DESCRIPTION OF INSTRUMENTATION*

The proposed seismic instrumentation should be discussed.* Seismic instrumentation such as triaxial peak accelerographs, triaxial time history accelerographs, and triaxial spectrum recorders that will be installed in selected Category I structures and on the selected Category I components should be described. The bases for selection of these structures and components and the location of instrumentation, as well as the extent to which this instrumentation will be employed to verify the seismic analyses following a seismic event, should be specified.

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* See for example, U.S. NRC Regulatory Guide 1.12, entitled, "Instrumentation for Earthquakes."

### *7.2 CONTROL ROOM OPERATOR NOTIFICATION*

The provisions that will be used to inform the control room operator of the value of the peak acceleration level and the input response spectra values shortly after occurrence of an earthquake should be described. The bases for establishing predetermined values for activating the readout of the seismic instrument to the control room operator should be included.

### *7.3 COMPARISON OF MEASURED AND PREDICTED RESPONSES*

Provide the criteria and procedures that will be used to compare measured responses of Category I structures and selected components in the event of an earthquake with the results of the seismic system and subsystem analyses.

## *8 REGULATIONS*

A list of codes, standards, specifications, regulations, general design criteria, and other industry standards used in the design, fabrication, and construction should be provided. The specific edition should be identified.

## *9 REFERENCES*

A list of references used in the report should be provided.

Section *9* concludes the contents of the applicant's report where the preface "3" has been omitted for simplicity (see page 9, section 3).

# 4. REFERENCES

American National Standards Institute, (1982), "Minimum Design Loads for Buildings and Other Structures," ANSI A58.1-1982, March, 100 pp.

Department of Transportation, (1980), "Liquefied Natural Gas Facilities; New Federal Safety Standards," 49 CFR Part 193, Research and Special Programs Administration, in Federal Register, Vol. 45, No. 29, Monday, February 11, 1980, pp. 9184 - 9237.

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International Conference of Building Officials, (1982), Uniform Building Code, 1982 Edition, Whittier, California, 780 pp.

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Newmark, N. M., (1976), "A Rationale for Development of Design Spectra for Diablo Canyon Reactor Facility," Report to the U.S. Nuclear Regulatory Commission, September, 18 pp. and figures.

Newmark, N. M., (1978), "Prepared Testimony of Nathan M. Newmark on Behalf of Pacific Alaska LNG Associates and Western LNG Terminal Associates," before the California Public Utilities Commission, November, 1978, Los Angeles, 10 pp. and attachments.

Newmark, N. M. and Hall, W. J. (1976), "Earthquake Resistant Design of Nuclear Power Plants," Proceedings of an Inter-Governmental Conference on Assessment and Mitigation of Earthquake Risks, UNESCO, Paris, February, pp. 198-218.

NFPA Standard 59A, "Production, Storage, and Handling of Liquefied Natural Gas (LNG), 1979 Edition.

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Young, G. A., (1977), "Evaluation of Seismic Criteria and Design Concepts for Point Conception LNG Import Terminal-Environmental Impact Report," Report R-7744-4496 prepared for Arthur D. Little, Inc. Cambridge, Massachusetts, by Agbabian Associates, 100 pp.

U.S. Nuclear Regulatory Commission, (1982), "Reactor Site Criteria; Appendix A - Seismic and Geologic Siting Criteria for Nuclear Power Plants." 10 CFR, Part 100, pp. 672-680.

U.S. Nuclear Regulatory Commission, (1978), "Seismic Design Classification," Regulatory Guide 1.29, Revision 3, September, 3 pp.

U.S. Nuclear Regulatory Commission, (1978), "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants," Regulatory Guide 1.70, Revision 3, November.

# APPENDIX A

## DoT LNG SAFETY STANDARDS, SUBPART B

## Subpart B—Siting Requirements

**§ 193.2051 Scope.**

This subpart prescribes siting requirements for the following LNG facilities: Containers and their impounding systems, transfer systems and their impounding systems, emergency shutdown control systems, fire control systems, and associated foundations, support systems, and normal or auxiliary power facilities necessary to maintain safety.

(49 U.S.C. 1674a; 49 CFR 1.53 and Appendix A of Part 1)

[Amdt. 193-1, 45 FR 57418, Aug. 28, 1980]

**§ 193.2055 General.**

An LNG facility must be located at a site of suitable size, topography, and configuration so that the facility can be designed to minimize the hazards to persons and offsite property resulting from leaks and spills of LNG and other hazardous fluids at the site. In selecting a site, each operator shall determine all site-related characteristics which could jeopardize the integrity and security of the facility. A site must provide ease of access so that personnel, equipment, and materials from offsite locations can reach the site for fire fighting or controlling spill associated hazards or for evacuation of personnel.

**§ 193.2057 Thermal radiation protection.**

(a) *Thermal exclusion zone.* Each LNG container and LNG transfer system must have a thermal exclusion zone in accordance with the following:

(1) Within the thermal exclusion zone, the impounding system may not be located closer to targets listed in paragraph (d) of this section than the exclusion distance "d" determined according to this section, unless the target is a pipeline facility of the operator.

(2) If grading and drainage are used under § 193.2149(b), operators must comply with the requirements of this section by assuming the space needed for drainage and collection of spilled liquid is an impounding system.

(b) *Measurement.* The exclusion distance "d" is measured along the line (PT), as shown in the following impoundment diagram, where the following apply:

(1) T is a point on the target that is closest to (P).

(2) D is a point closest to (T) on the top inside edge of the innermost dike.

(3) $\theta$ is one of the following angles with the vertical, to account for flame tilt and potential preignition vapor formation:

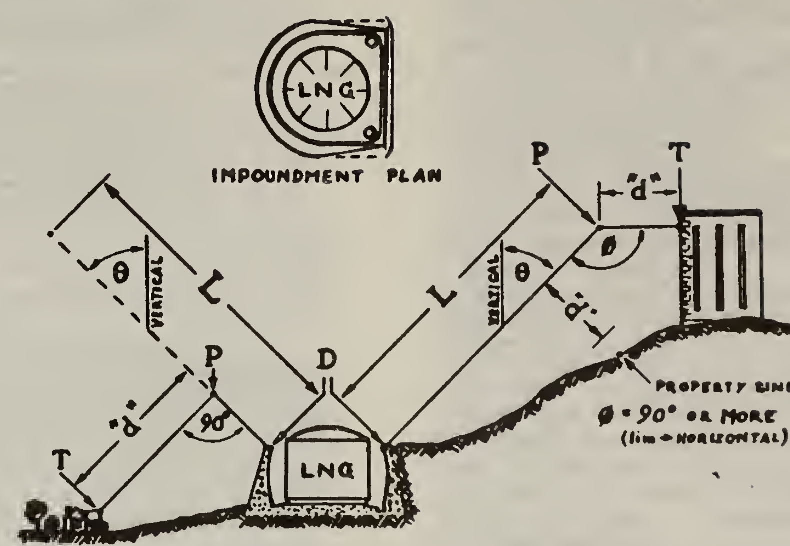
(i) An assumed angle of $(\theta)=45°$; or

(ii) An angle determined in accordance with a mathematical model that meets the criteria of paragraph (c)(2) of this section, using the maximum wind speed that is exceeded less than 5 percent of the time based on recorded data for the area.

(4) L is one of the following lengths to account for flame height:

(i) An assumed length of $(L)=6(A/\pi)^{.5}$, where (A) is the horizontal area across the impounding space measured at the lowest point along the top inside edge of the dike; or

(ii) A length determined in accordance with a mathematical model that meets the criteria of paragraph (c)(2) of this section, using appropriate parameters consistent with the time




IMPOUNDMENT & TOPOGRAPHY
ELEVATION PROFILE

period that a target could be subjected to exposure before harm would result.

(5) PD is a line of length (L) or less, lying at angle $\theta$ in the vertical plane that intersects points (D) and (T).

(6) PT is a line lying in the vertical plane of line (PD), that:

(i) Is perpendicular to line (PD) when (PD) is less than (L); or

(ii) Has an angular elevation not above the horizontal at (P) when (PD) equals (L);

(7) P is the point where (PT) and (PD) intersect.

(c) *Exclusion distance length.* The length of an exclusion distance for each impounding space may not be less than the distance "d" determined in accordance with one of the following:

(1) $d=(f)(A)^{0.5}$, where

A=the largest horizontal area across the impounding space measured at the lowest point along the top inside edge of the dike.

f=values for targets prescribed in paragraph (d) of this section.

(2) Determine "d" from a mathematical model for thermal radiation and other appropriate fire characteristics which assures that the incident thermal flux levels in paragraph (d) of this section are not exceeded. The model must:

(i) Use atmospheric conditions which, if applicable, result in longer exclusion distances than other atmospheric conditions occurring at least 95 percent of the time based on recorded data for the site area;

(ii) Have been evaluated and verified by testing at a scale, considering scaling effects, appropriate for the range of application;

(iii) Have been submitted to the Director for approval, with supportive data as necessary to demonstrate validity; and

(iv) Have received approval by the Director.

(d) *Limiting values for incident radiant flux on offsite targets.* The maximum incident radiant flux at an offsite target from burning of a total spill in an impounding space must be limited to the distances in paragraph (c) of this section using the following values of "(f)" or "Incident Flux":

| Offsite target | (f) | Incident flux Btu/ft.² hour |
|---|---|---|
| (1) Outdoor areas occupied by 20 or more persons during normal use, such as beaches, playgrounds, outdoor theaters, other recreation areas or other places of public assembly | (3) | 1,600 |
| (2) Buildings that are used for residences, or occupied by 20 or more persons during normal use | (1.6) | 4,000 |
| (3) Buildings made of cellulosic materials or are not fire resistant or do not provide durable shielding from thermal radiation that: | | |
| (i) Have exceptional value, or contain objects of exceptional value based on historic uniqueness described in Federal, State, or local registers: | | |
| (ii) Contain explosive, flammable, or toxic materials in hazardous quantities; or | | |
| (iii) Could result in additional hazard if exposed to high levels of thermal radiation | (1.6) | 4,000 |
| (4) Structures that are fire resistant and provide durable shielding from thermal radiation that have the characteristics described in paragraphs (3)(i) through (3)(iii) above | (1.1) | 6,700 |
| (5) Public streets, highways, and mainlines of railroads— | (1.1) | 6,700 |
| (6) Other structures, or if closer to (P), the right-of-way line of the facility | (0.8) | 10,000 |

(49 U.S.C. 1674a; 49 CFR 1.53 and Appendix A of Part 1)

[45 FR 9203, Feb. 11, 1980, as amended by Amdt. 193-1, 45 FR 57418, Aug. 28, 1980]

**§ 193.2059 Flammable vapor-gas dispersion protection.**

(a) *Dispersion exclusion zone.* Except as provided by paragraph (e) of this section, each LNG container and LNG transfer system must have a dispersion exclusion zone with a boundary described by the minimum dispersion distance computed in accordance with this section. The following are prohibited in a dispersion exclusion zone unless it is an LNG facility of the operator:

(1) Outdoor areas occupied by 20 or more persons during normal use, such as beaches, playgrounds, outdoor theaters, other recreation areas, or other places of public assembly.

(2) Buildings that are:

(i) Used for residences;

(ii) Occupied by 20 or more persons during normal use;

(iii) Contain explosive, flammable, or toxic materials in hazardous quantities;

(iv) Have exceptional value or contain objects of exceptional value based on historic uniqueness described in Federal, State, or local registers; or

(v) Could result in additional hazard if exposed to a vapor-gas cloud.

(b) *Measuring dispersion distance.* The dispersion distance is measured radially from the inside edge of an impounding system along the ground contour to the exclusion zone boundary.

(c) *Computing dispersion distance.* A minimum dispersion distance must be computed for the impounding system. If grading and drainage are used under § 193.2149(b), operators must comply with the requirements of this section by assuming the space needed for drainage and collection of spilled liquid is an impounding system.

Dispersion distance must be determined in accordance with the following dispersion parameters, using applicable parts of the mathematical model in Appendix B of the report, "Evaluation of LNG Vapor Control Methods," 1974, or a model for vapor dispersion which meets the requirements of paragraphs (ii) through (iv) in § 193.2057(c)(2):

(1) Average gas concentration in air = 2.5 percent.

(2) Dispersion conditions are a combination of those which result in longer predicted downwind dispersion distances than other weather conditions at the site at least 90 percent of the time, based on U.S. Government weather data, or as an alternative where the model used gives longer distances at lower wind speeds, Category F atmosphere, wind speed = 4.5 miles per hour, relative humidity equals 50.0 percent, and atmospheric temperatures = 0.0 C.

(3) Dispersion coordinates y, z, and H, where applicable, = 0.

(d) *Vaporization design rate.* In computing dispersion distance under paragraph (c) of this section, the following applies:

(1) Vaporization results from the spill caused by an assumed rupture of a single transfer pipe (or multiple pipes that lack provisions to prevent parallel flow) which has the greatest overall flow capacity, discharging at maximum potential capacity, in accordance with the following conditions:

(i) The rate of vaporization is not less than the sum of flash vaporization and vaporization from boiling by heat transfer from contact surfaces during the time necessary for spill detection, instrument response, and automatic shutdown by the emergency shutdown system but, not less than 10 minutes, plus, in the case of impounding systems for LNG storage tanks with side or bottom penetrations, the time necessary for the liquid level in the tank to reach the level of the penetration or equilibrate with the liquid impounded assuming failure of the internal shutoff valve.

(ii) In determining variations in vaporization rate due to surface contact, the time necessary to wet 100 percent of the impounding floor area shall be determined by equation C-9 in the report "Evaluation of LNG Vapor Control Methods," 1974, or an alternate model which meets the requirements of paragraphs (ii) through (iv) in § 193.2057(c)(2).

(iii) After spill flow is terminated, the rate of vaporization is vaporization of the remaining spillage, if any, from boiling by heat transfer from contact surfaces that are reducing in area and temperature as a function of time.

(iv) Vapor detention space is all space provided for liquid impoundment and vapor detention outside the component served, less the volume occupied by the spilled liquid at the time the vapor escapes the vapor detention space.

(2) The boiling rate of LNG on which dispersion distance is based is determined using the weighted average value of the thermal properties of the contact surfaces in the impounding space determined from eight representative experimental tests on the materials involved. If surfaces are insulated, the insulation must be designed, installed, and maintained so that it will retain its performance characteristics under spill conditions.

(e) *Planned vapor control.* An LNG facility need not have a dispersion exclusion zone if the Director finds that compliance with paragraph (a) of this section would be impractical and the operator prepares and follows a plan for controlling LNG vapor that is found acceptable by the Director. The plan must include circumstances under which LNG vapor is controlled to preclude the dispersion of a flammable mixture from the LNG facility under all predictable environmental conditions that could adversely affect control. The reliability of the method of control must be demonstrated by testing or experience with LNG spills.

(49 U.S.C. 1674a; 49 CFR 1.53 and Appendix A of Part 1)

[45 FR 9203, Feb. 11, 1980, as amended by Amdt. 193-1, 45 FR 57418, Aug. 28, 1980]

**§ 193.2061 Seismic investigation and design forces.**

(a) Except for shop fabricated storage tanks of 70,000 gallons or less capacity mounted within 2 feet of the ground, if an LNG facility is located at a site in Zone 0 or 1 of the "Seismic Risk Map of the United States," UBC, each operator shall determine, based on a study of faults, hydrologic regime, and soil conditions, whether a potential exists at the site for surface faulting or soil liquefaction.

(b) Subject to paragraph (f) of this section, LNG facilities must be designed and built to withstand, without loss of structural or functional integrity, the following seismic design forces, as applicable:

(1) For LNG facilities (other than shop fabricated storage tanks of 70,000 gallons or less capacity mounted within 2 feet of the ground) located at a site in Puerto Rico in Zone 2, 3, or 4 of the "Seismic Risk Map of the United States," or at a site determined under paragraph (a) of this section to have a potential for surface faulting or soil liquefaction, the forces that could reasonably be expected to occur at the foundation of the facility due to the most critical ground motion, motion amplification, permanent differential ground displacement, soil liquefaction, and symmetric and assymmetric reaction forces resulting from hydrodynamic pressure and motion of contained liquid in interaction with the facility structure.

(2) For all other LNG facilities, the total lateral force set forth in UBC, Volume 1, corresponding to the zone of the "Seismic Risk Map of the United States" in which the facility is located, and a vertical force equal to the total lateral force.

(c) Each operator of an LNG facility to which paragraph (b)(1) of this section applies shall determine the seismic design forces on the basis of a detailed geotechnical investigation and in accordance with paragraphs (d) and (e) of this section. The investigation must include each of the following items that could reasonably be expected to affect the site and be sufficient in scope to identify all hazards that could reasonably be expected to affect the facility design:

(1) Identification and evaluation of faults, Quaternary activity of those faults, tectonic structures, static and dynamic properties of materials underlying the site, and, as applicable, tectonic provinces within 100 miles of the site;

(2) Identification and evaluation of all historically reported earthquakes which could affect the determination under this section of the most critical ground motion or differential displacement at the site when correlated with particular faults, tectonic structures, and tectonic provinces, as applicable; and

(3) Identification and evaluation of the hydrologic regime and the potential of liquefaction-induced soil failures.

(d) The most critical ground motion must be determined in accordance with paragraph (e) of this section either:

(1) Probabilistically, when the available earthquake data are sufficient to show that the yearly probability of exceedance of most critical ground motion is $10^{-4}$ or less; or

(2) Deterministically, when the available earthquake data are insufficient to provide probabilistic estimates, with the objective of determining a most critical ground motion with a yearly probability of exceedance of $10^{-4}$ or less.

(e) The determination of most critical ground motion, considering local and regional seismological conditions, must be made by using the following:

(1) A regionally appropriate attenuation relationship, assuming that earthquakes occur at a location on a fault, tectonic structure, or tectonic province, as applicable, which would cause the most critical seismic movement at the site, except that where epicenters of historically reported earthquakes cannot be reasonably related to known faults or tectonic structures, but are recognized as being within a specific tectonic province which is within 100 miles of the site, assume that those earthquakes occur within their respective provinces at a source closest to the site.

(2) A horizontal design response spectrum determined from the mean plus one standard deviation of a free-field horizontal elastic response spectra whose spectral amplitudes are consistent with values expected for the most critical ground motion.

(3) A vertical design response spectrum that is either two-thirds of the amplitude of the horizontal design response spectrum at all frequencies or equal to the horizontal design response spectrum where the site is located within 10 miles of the earthquake source.

(f) An LNG storage tank or its impounding system may not be located at a site where an investigation under paragraph (c) of this section shows that any of the following conditions exists unless the Director grants an approval for the site:

(1) The estimated design horizontal acceleration exceeds 0.8g at the tank or dike foundation.

(2) The specific local geologic and seismic data base is sufficient to predict future differential surface displacement beneath the tank and dike area, but displacement not exceeding 30 inches cannot be assured with a high level of confidence.

(3) The specific local geologic and seismic data base is not sufficient to predict future differential surface displacement beneath the tank and dike area, and the estimated cumulative displacement of a Quaternary fault within one mile of the tank foundation exceeds 60 inches.

(4) The potential for soil liquefaction cannot be accommodated by design and construction in accordance with paragraph (b)(1) of this section.

(g) An application for approval of a site under paragraph (f) of this section must provide at least the following:

(1) A detailed analysis and evaluation of the geologic and seismic characteristics of the site based on the geotechnical investigation performed under paragraph (c) of this section, with emphasis on prediction of near-field seismic response.

(2) The design plans and structural analysis for the tank, its impounding system, and related foundations, with a report demonstrating that the design requirements of this section are satisfied, including any test results or other documentation as appropriate.

(3) A description of safety-related features of the site or designs, in addition to those required by this part, if applicable, that would mitigate the potential effects of a catastrophic spill (e.g., remoteness or topographic features of the site, additional exclusion distances, or multiple barriers for containing or impounding LNG).

(h) Each container which does not have a structurally liquid-tight cover must have sufficient freeboard with an appropriate configuration to prevent the escape of liquid due to sloshing, wave action, and vertical liquid displacement caused by seismic action.

(49 U.S.C. 1674a; 49 CFR 1.53 and Appendix A of Part 1)

[45 FR 9203, Feb. 11, 1980, as amended by Amdt. 193-1, 45 FR 57419, Aug. 28, 1980]

**§ 193.2063 Flooding.**

(a) Each operator shall determine the effects of flooding on an LNG facility site based on the worst occurrence in a 100-year period. The determination must take into account:

(1) Volume and velocity of the floodwater;

(2) Tsunamis (local, regional, and distant);

(3) Potential failure of dams;

(4) Predictable land developments which would affect runoff accumulation of water; and

(5) Tidal action.

(b) The effect of flooding determined under paragraph (a) of this section must be accommodated by location or design and construction, as applicable, to reasonably assure:

(1) The structural or functional integrity of LNG facilities; and

(2) Access from outside the LNG facility and movement of personnel and equipment about the LNG facility site for the control of fire and other emergencies.

**§ 193.2065 Soil characteristics.**

(a) Soil investigations including borings and other appropriate tests must be made at the site of each LNG facility to determine bearing capacity, settlement characteristics, potential for erosion, and other soil characteristics applicable to the integrity of the facility.

(b) The naturally occurring or designed soil characteristics at each LNG facility site must provide load bearing capacities, using appropriate safety factors, which can support the following loads without excessive lateral or vertical movement that causes a loss of the functional or structural integrity of the facility involved:

(1) Static loading caused by the facility and its contents and any hydrostatic testing of the facility; and

(2) Dynamic loading caused by movement of contents of the facility during normal operation, including flow, sloshing, and rollover.

**§ 193.2067 Wind forces.**

(a) LNG facilities must be designed to withstand without loss of structural or functional integrity:

(1) The direct effect of wind forces;

(2) The pressure differential between the interior and exterior of a confining, or partially confining, structure; and

(3) In the case of impounding systems for LNG storage tanks, impact forces and potential penetrations by wind borne missiles.

(b) The wind forces at the location of the specific facility must be based on one of the following:

(1) For shop fabricated containers of LNG or other hazardous fluids with a capacity of not more than 70,000 gallons, applicable wind load data in ANSI A 58.1, 1972 edition.

(2) For all other LNG facilities—

(i) An assumed sustained wind velocity of not less than 200 miles per hour, unless the Director finds a lower velocity is justified by adequate supportive data; or

(ii) The most critical combination of wind velocity and duration, with respect to the effect on the structure, having a probability of exceedance in a 50-year period of 0.5 percent or less, if adequate wind data are available and the probabilistic methodology is reliable.

(49 U.S.C. 1674a; 49 CFR 1.53 and Appendix A of Part 1)

[45 FR 9203, Feb. 11, 1980, as amended by Amdt. 193-1, 45 FR 57419, Aug. 28, 1980]

**§ 193.2069 Other severe weather and natural conditions.**

(a) In addition to the requirements of §§ 193.2061, 193.2063, 193.2065, and 193.2067, each operator shall determine from historical records and engineering studies the worst effect of other weather and natural conditions which may predictably occur at an LNG facility site.

(b) The facility must be located and designed so that such severe conditions cannot reasonably be expected to result in an emergency involving the factors listed in § 193.2063(b).

**§ 193.2071 Adjacent activities.**

(a) Each operator shall determine that present and reasonably foreseeable activities adjacent to an LNG facility site that could adversely affect the operation of the LNG facility or the safety of persons or offsite property, if damage to the facility occurs.

(b) An LNG facility must not be located where present or projected offsite activities would be reasonably expected to—

(1) Adversely affect the operation of any of its safety control systems;

(2) Cause failure of the facility; or

(3) Cause the facility not to meet the requirements of this part.

**§ 193.2073 Separation of facilities.**

Each LNG facility site must be large enough to provide for minimum separations between facilities and between facilities and the site boundary to—

(a) Permit movement of personnel, maintenance equipment, and emergency equipment around the facility; and

(b) Comply with distances specified in sections 2-2.4 through 2-2.7 of NFPA 59A.

APPENDIX B. CATEGORIZATION OF LNG STRUCTURES, COMPONENTS AND SYSTEMS

For purposes of design, all structures, components, and systems important to normal LNG facility operations shall be classified into one of three design categories that are defined as follows:

Category I: All structures, components, and systems which perform a vital safety-related function, including the LNG storage containers, their impounding systems, and hazard protection systems, shall be classified Category I.

Category II: All structures, components, and systems not included in Category I which are required to maintain continued safe plant operation shall be classified Category II.

Category III: All structures, components, and systems not included in Categories I and II, but which are essential for maintaining support of normal plant operations, shall be classified Category III. Category III items shall be designed in accordance with the provisions of the UBC, ANSI, API, or other applicable national, state, or local standards and codes.

Supporting Elements and Enclosures

A structure, component, or system of a given category may be supported or enclosed by a structure classified in a different category, provided it is demonstrated that the supported item can maintain its functional requirements specified by its design category.

The following structures, components, systems, etc., are divided into the appropriate categories.

CATEGORY I Structures, Components, and Systems:

- LNG Storage Tanks and Their Foundations
- LNG Storage Tank Containment Dikes
- Diesel Driven Power Generator(s) and Fuel Supply at the Dock and Plant
- Emergency Lighting
- Fire Protection Systems, to include
  - Building Sprinkler systems
  - Halon System
  - Interconnecting Wiring for Above
  - Dry Chemical Units
  - Fire Retardant Foam Units
- Firewater Systems that include
  - Dock firewater pump (diesel driven)
  - Fire hydrants
  - Firewater piping systems
  - Plant firewater pump (diesel driven)
  - Seawater intake line reinforced concrete, prestressed concrete, etc.

Seawater supply pump structure
Seawater velocity cap
Firewater supply, if not seawater

Fire And Leak Detection Systems That Include:
- Combustible gas detectors
- Detection panel in control room
- Fire alarm boxes
- High temperature detectors
- Low temperature detectors
- Smoke detectors
- Ultraviolet detectors
- Interconnecting wiring for all the above items

Radio Communications System
- All permanent mounted wireless radios

Shutdown System
- Control valves
- Instrumentation
- Related control panel

Uninterruptible Power System (U.P.S.)
- Batteries (in rack)
- Battery charger
- U.P.S. inverter

Vent And Relief System
- All liquid and vapor relief valves in natural gas service

CATEGORY II Structures, Components, and Systems:

LNG Sendout System
- Controls
- Fired vaporizers
- Fuel gas system for fired equipment
- Instrumentation
- Interconnecting piping systems
- Metering system
- Odorizing system
- Primary LNG pumps
- Seawater vaporizers
- Secondary LNG pumps
- Trim heater
- Vapor absorber

LNG Unloading And Transfer System
- Controls
- Instrumentation
- LNG Recirculation System
- Offshore piping from dock to abutment
- Onshore piping systems from abutment to storage tanks
- Unloading arms

Control Building

Electrical Distribution Systems

Fire Station/Warehouse

Instrument & Utility Air System

Afterfilter
Air receiver
Compressors
Controls
Dryer
Instrumentation
Piping systems

Main Control Panel And Components

Marine Trestle And Dock (includes structures such as unloading platform, service platform, trestle, dock operator's building and control tower on dock)

Nitrogen Systems

Power Generation System
- Controls
- Fuel gas heater
- Fuel gas system
- Instrumentation
- Power generation building
- Standby power generators

Seawater Supply And Return System
- Controls
- Instrumentation
- Piping to vaporizers
- Seawater pumps
- Seawater return line
- Screening equipment

Standby Plant Lighting

Substation Buildings

Vapor Compression System
- Compressor suction drum
- Controls
- Instrumentation
- Interconnecting piping systems
- Unloading compressors

| | |
|---|---|
| CATEGORY III | Structures, Components and Systems:<br>Administration Building<br>Bunker Fuel System<br>Diesel Fuel System except as needed for Category I or II equipment<br>Dock Service Equipment<br>Incoming Electrical Power Systems Including Switchyard<br>Normal Plant Lighting System<br>Waste Treatment Building |

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This report describes data needed by the Federal Energy Regulatory Commission for the seismic review of Liquefied Natural Gas (LNG) facilities and is intended to expedite the certification process of the Federal Energy Regulatory Commission. It uses a format familiar to those industry representatives and their consultants who work on siting other safety-related structures. Available state and Federal regulations were reviewed for format and type of information required to develop a source document which can be used to establish a consistent format and content for applications in their submittal of the necessary geological-structural-seismic information required to analyze sites for LNG facilities. Design criteria and levels of safety to be used in analyzing sites were not considered.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

LNG facilities; seismic design; Federal Energy Regulatory Commission; site investigation and data requirements.

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